HERA User Manual

The commissioning team*

version 1.9

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1 Introduction

The **HE**terodyne **R**eceiver **A**rray HERA is a receiver system with 18 SIS mixers tunable from 215 to 272 GHz. The main purpose of this first multi–beam spectral line receiver on the 30m telescope is to allow, together with the related backends, for rapid raster and on–the–fly imaging of spectral lines in the 1.3mm atmospheric window. Other more particular observing modes (continuum measurements and mapping, polarization measurements and optimized wobbling on point sources) are possible but not yet offered as standard observing modes [1]

HERA has been embedded into the existing setup of the 30m telescope as much as possible. Observing commands (OBS) and data structure follow closely that of the single pixel spectroscopy receivers. Only where necessary, new or modified commands have been introduced and only these will be described in this manual. However in order to make efficient use of HERA, the user needs to be aware of some basic technical aspects of the instrument, the particularities of the data stream and typical observing strategies. The current version of the manual includes the description of observing with both polarizations and the new WILMA wide band correlator. Complementary information can also be found in Schuster et al. 2004 A&A (see IRAM 30m webpage). Suggestions for improving this manual are welcome and should be addressed to A. Sievers.

2 Technical Description

HERA has nine dual polarization pixels (18 Channels) arranged in the form of a square center–filled 3×3 array. The distance between pixels on the sky is $24''$, i.e. close to twice the beam width (FWHP) at 230 GHz. By means of a quasi-optical K–mirror derotator this pattern can be placed at any position

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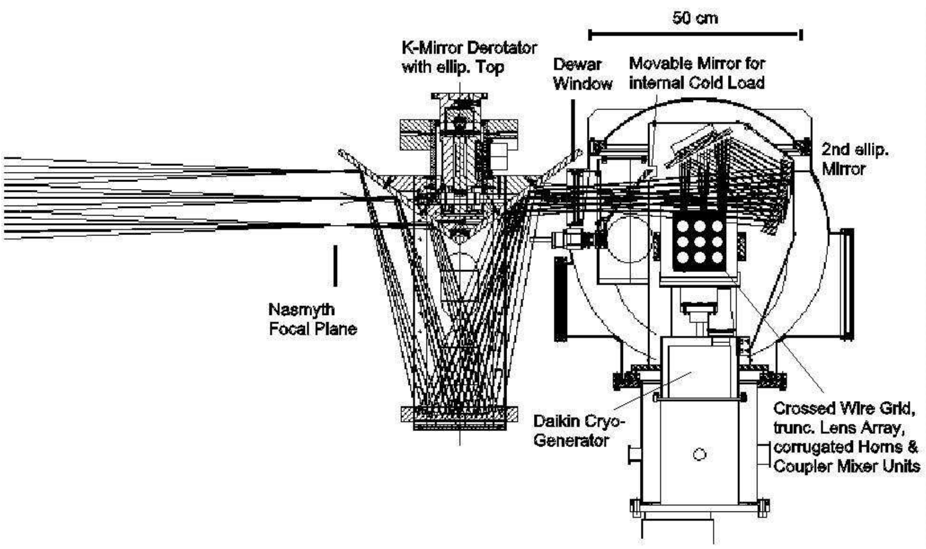

Figure 1: Optical layout of HERA, including the derotator.

angle on the sky (see also sect. 4). The two polarization modules are named HERA1 and HERA2. Both modules can independently be tuned to different sky freqencies and be attached to different backends.

2.1 Cryogenics

HERA is cooled with a 3 stage closed cycle refrigerator system (DAIKIN) which greatly reduced technical overhead times and running costs. The receiver can be warmed up in 12 hours and be cooled down within 36 hours. Usually the receiver is kept cold for periods of at least 3 months followed by a maintenance period of typically 4-5 days.

2.2 Optics

HERAs optics (fig. 1) is designed to give maximum point source coupling of the individual beams and at the same time to reduce deformations of the array geometry irrespectively of the position of the K–mirror derotator. With this concept it is possible to obtain extremely simple observation procedures as it is not necessary to make field maps for calibration of the array parameters or other particular measurements before mapping. The positions of the elements are simple functions of the position of the central elements and the chosen derotation angle. The optics of HERA is largely reflective which reduces baseline ripples due to standing waves by a large amount.

2.3 Optical data and efficiencies

An internal cold/hot load system is integrated into HERA and allows to calibrate all 18 channels in a single hot/cold load procedure. Due to its dual polarization and derotation concept HERA cannot be combined with other receivers. Switching between HERA and other receivers is however possible within about 10 minutes. HERA1 pixels have vertical (in the Nasmyth cabin) polarization and share the same local oscillator. They have thus the same sky frequency. HERA2 has horizontal polarization and a different LO, its nine pixels can thus be tuned to a sky frequency, different from that of the vertical pixels. The relative pointing of the two polarization modules is better than 1.2". Both modules share the same focus setting.

The efficiency related parameters at 230 GHz are :

cold load temperature	~ 97 K
image band gain	~ 0.1
forward efficiency	$F_{eff} = 0.90$
main beam efficiency	$B_{eff} = 0.52$
Beam size at 230 GHz	$11.7''$

2.4 Derotator

The Derotator is an optical ensemble in front of the HERA cryostat (Fig. 1 which allows to compensate for the rotation of the astronomical object in the focal plane of the telescope. This rotation is due to the general characteristics of an AZ-Alt-mounted Nasmyth-telescope and a function of actual Azimuth and Elevation. The derotator commpensates this rotation by computer controlled movements. The end-effect is, that the pixel pattern (and polarization) can be kept fixed on the sky (in the equatorial system or alternatively in the horizontal system). Fields can therefore be easily sampled homogeniously and a great number of particular observing strategies are possible. The derotator is constructed as a K-mirror, a device which is frequently used in optical astronomy and the first implemented in the millimiter range for HERA.

To make efficient use of HERA it is essential that the user integrates a minimum of information about the derotator before observing.

The current control software allows to keep the HERA pixel pattern stationary, i.e. *derotate* various hour angle dependent rotations, in the following three coordinate systems.

F	Frame	Nasmyth coord.	sim. Bolo. (stationary in the receiver cabin)
H	Horizontal	Az., El. Syst.	usefull to align array with wobbler dir.
S	Sky	RA, Dec. Syst	most common mode

The derotator is steered from OBS by entering, e.g.

OBS> `set derot` β `S`

where S makes the derotator tracking the sky rotation and β is an angle (constant in time) by which the HERA pixel pattern is rotated with respect to the equatorial system (counting east from north). The derotator command is executed when a "LOAD" is made in the telescope control or in other words before a new scan is started.

As an example, commanding $\beta = 0°$. keeps the 9 pixel pattern of HERA stationary in the equatorial system so that the horizontal rows of 3 pixels (e.g. pixels No. 7, 5 , and 2) are always parallel to right ascension, like shown in Fig. 4. In this seemingly simple setup the HERA center pixel (No. 1 in Fig. 4) is on the telescope's pointing axis, and all peripheral pixels have fixed (in time) offsets in the equatorial system of $\Delta\alpha$ and $\Delta\delta$ of 0 or $\pm 24''$ according to Fig. 4.

The angle by which the derotator can be physically rotated in the frame system is limited to $\pm 84°$. As the K-mirror multiplys rotation angles by a factor of two this allows to rotate the pixel pattern on the sky within a range of 336 degrees. However while tracking it might happen that the derotator approaches these physical limits. To avoid loss off data the observer should keep an eye on the newly installed HERA monitor webpage (ask the operator or the AOD to open this web page in the automatic update mode within the screen ensemble of the observer). The current angle and tracking system is displayed in the left upper corner of this webpage. When the DEROTATOR box is turning yellow the derotator is still tracking normally but its time for action. If it turnes red, tracking is off due to the mechanical limits. Mapping part of an extended source with the derotator stuck in a limit may result in un-reproducible distortions.

If the derotator angle displayed in the derotator window is close to a limit (yellow), the derotator should be rotated by 90° (Sky system) in the right direction. If the limit at $-84°$ is approached, set the angle to $\beta - 90°$ where β is the angle demanded by the mapping mode (see below).

A procedure is implemented in ASTRO which generates a plot of the derotator angle in the frame system as a function of time UT. Open the input window in ASTRO (Gildas version JAN02 and newer):

ASTRO> `input`

Then choose in the pull–down window `Pico Veleta` the item `Derotator angle`. This opens the input window where the source name (mandatory), the source position (format hh:mm.ss.s, dd:mm.ss.s), and the desired derotator angle (often simply "0"). After click on `GO` a plot of the derotator angle in the frame system is generated as a function of UT. Note that the sign of this angle is still inverted with respect to the correct angle displayed in the derotator window.

2.5 Mixers and RF performance

HERA uses waveguide SIS mixers which can be tuned in LSB or DSB mode. The coupling of local oscillator power is obtained over waveguide coupler modules. LSB is the normal and preferred tuning mode as it offers superior

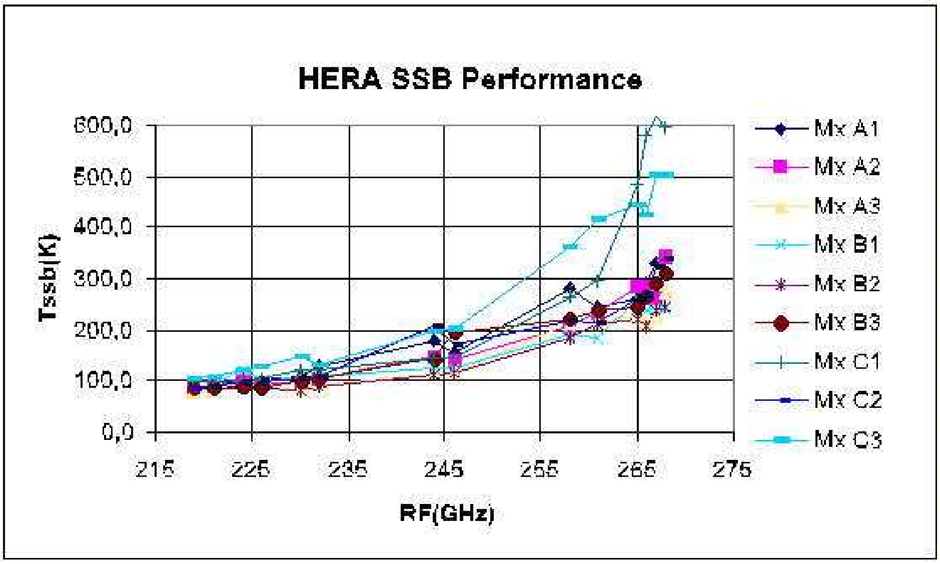

Figure 2: SSB receiver noise temperatures across the tuning range. These temperatures were measured in the laboratory in front of the dewar window.

overall system noise. However it must be recognized that LSB tuning results frequently in reduced total power stability which somtimes makes pointing on weak sources difficult.

The noise performance of HERA1 over the tuning range is given by the Fig. 2. HERA2 has a very similar performance for frequencies up to 230 GHz but is higher in noise above 230 GHz. In practice, these noise temperatures have to be increased by a factor of 1.15 if VESPA is used as the backend (IRAM's correlators are presently 2 bit 4 level). Another small increase (3. . . 5 K) comes from losses on the derotator mirrors. It is planned to upgrade the mixers of HERA in the future.

The local oscillator tuning range is 219 to 276 GHz. Taking the IF frequency of 4 GHz into account, this results in a RF tuning range of 215 to 272 GHz for LSB tuning (standard tuning mode). DSB tuning is also possible. The IF bandwidth is 1 GHz. Tuning is automatic and uses look–up tables. Because these look-up tables have not yet been finalized the tuning has to be prepared in advance, apart from a series of heavily used frequencies. [2]

The image rejection is about 10dB in LSB tuning mode for all pixels ($Gn_i = 0.1$) and set globally for both modules at the present time. A more precise rejection measurement using a line injection device is currently underway and will ultimately allow to retrieve individual rejections for each pixel from a look-up table at each frequency. The limited accuracy of the knowledge of sideband rejection leads to relative calibration errors in the

[2] The present look-up table of sky frequencies in GHz is: 217.0 219.0 221.0 224.0 225.0 226.0 230.0 232.0 244.0 245.0 246.0 258.0 260.0 261.0 265.0 266.0 267.0 268.0. The frequency you want to use should be within a range of ± 0.6 GHz.

range of 0-10% . For high signal to noise mapping it is therefore recommended to undertake some additional steps for relative calibration or "flat-fielding" (see Sect XX).

3 Basic calibration observations

This section describes the basic observations which serve to measure the telescope pointing and focus and to calibrate the antenna temperature scale.

3.1 Pointing

Pointing with the central pixel.
Default pointing scans are made with the central pixel of HERA1 and the usual command:

OBS> `point`

Pointing on the central HERA2 pixel can be made with the command:

OBS> `point` 14

The HERA pixel pattern is shown shown in Fig. 3 as it appears in the receiver cabin (Nasmyth coordinations) before rotation in the derotator assembly (see sect. 2.4), when looking towards the subreflector . The central pixels of HERA1, No. 5, and of HERA2, No. 14, are aligned with the telescope's pointing axis and with the other SIS receivers to within better than $\leq 2''$. This degree of alignment was measured to be independent of the actual derotator position. **For pointing with central pixels it is therfore not necessary to set a particular derotator angle or tracking system** and the standard pointing model can be used unmodified for HERA. This includes on–line display of the central pixel on the RED screen and the Gaussian fits for deriving the pointing offsets. The resulting correction parameters can be taken into account by the usual command:

OBS> `corr f f`

Pointing with off elements. Although somewhat more complicated pointing with HERA is possible also with offset pixels. The results are always referred to the position of the central beam. This option may be used if an off–pixel has a much better continuum sensitivity or stability than the central pixel. Right now a few commands have to be entered in OBS to make pointings with off–elements:

OBS> `set derot 0 F`

OBS> `set recoff` x_n y_n

OBS> `point` n

OBS> `set recoff 0 0`

The first command sets the derotator to zero degrees, its default position (no rotation) in the Nasmyth cabin. Next, OBS is informed about the offset in Nasmyth coordinates of the receiver (pixel) used for pointing. Then OBS executes the pointing with pixel No. n including an on–line display of that pixel. Again, the resulting pointing fits can directly be accepted as a pointing corrections for the array with `corr F F` (no further offsets have to be given). Fig. 3 and Tab. 1 show the correspondence between pixel No. n and their offsets H and V in Nasmyth coordinates, **note** that we have renumbered the continuum pixels for HERA1. The arguments x_n, y_n of the OBS `set recoff` command have the opposite signs, as these arguments are offsets for the telescope pointing which bring off–pixel n back onto the pointing axis.

The nominal offsets of the pixels as given in Tab. 1 have been determined from beam maps and are valid to a precision of better than $1''$. Do not confound these Nasmyth offsets (to be used only with the OBS command `set recoff`) with the offsets of the pixels from the pointing axis on the sky. In the horizontal system, the Nasmyth pixel pattern is rotated by the elevation angle. In the equatorial system, an additional rotation by the parallactic angle is made.

Table 1: HERA pixel pattern and corresponding spectrometer sections.

HERA1 pixel No.		1	2	3	4	5	6	7	8	9
HERA2 pixel No.		10	11	12	13	14	15	16	17	18
Nasmyth offsets	H	−24	−24	−24	0	0	0	+24	+24	+24
	V	−24	0	+24	−24	0	+24	−24	0	+24
`set recoff`	x_n	+24	+24	+24	0	0	0	−24	−24	−24
	y_n	+24	0	−24	24	0	−24	+24	0	−24
spectrometers										
VESPA V0(1 ... 4)		1H01	1H02	1H03	1H04	1H05	1H06	1H07	1H08	1H09
		2H01	2H02	2H03	2H04	2H05	2H06	2H07	2H08	2H09
WILMA WA		1H01	1H02	1H03	1H04	1H05	1H06	1H07	1H08	1H09
WILMA WB		2H01	2H02	2H03	2H04	2H05	2H06	2H07	2H08	2H09
filterbank 4M		1H01	1H02	1H03	1H04	1H05	1H06	1H07	1H08	1H09
		2H01	2H02	2H03	2H04	2H05	2H06	2H07	2H08	2H09

3.2 Focus

HERA's derotator re–images the telescope focal plane which is located about 28 cm in front of the derotator rotation axis, onto the dewar window. The separation between the HERA mixers and the subreflector is therefore considerably longer than for the other SIS receivers. Nevertheless, HERA was installed in such a way that its telescope focus setting of the secondary mirror is within 0.5 mm of that of the other receivers.

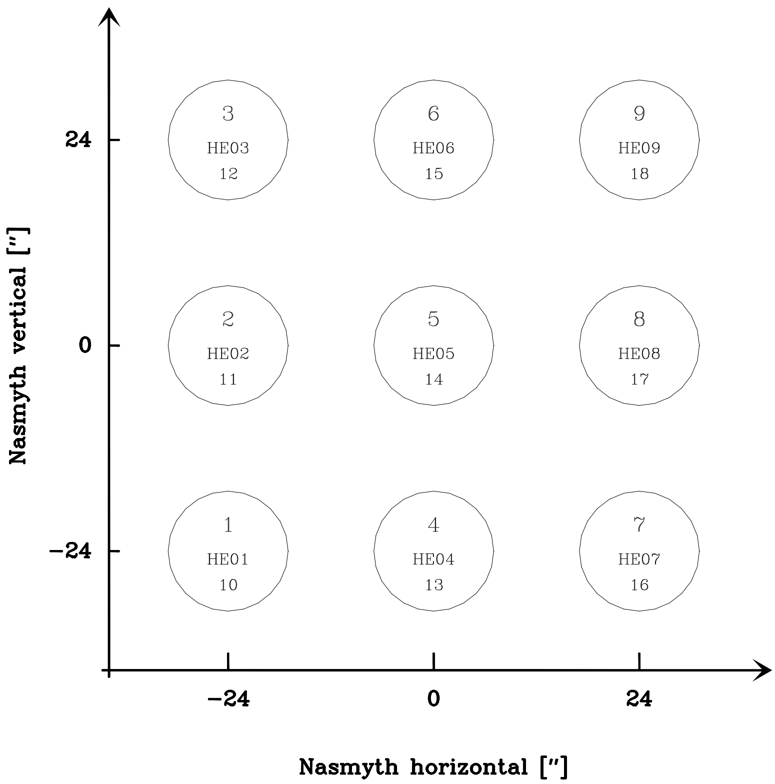

Figure 3: HERA beam pattern at the telescope focal plane in the Nasmyth cabin, viewed from the receiver. The derotator is at its default position (`set derot 0 F`). **This is not the sky pattern !**

The possibilities to focus HERA are quite similar to the pointing options. There is no difference to single beam receivers for focusing onto the central element, and one uses the OBS command `set recoff` to focus on off–elements.

To focus on off–center pixel No. n, e.g. because it is more stable in continuum than the center pixel, one goes through the following sequence of OBS commands:

```
set derot 0 F
set recoff xn yn
focus n
corr * * F           (if fit is satisfactory)
set recoff 0 0 (reset pointing offset for central pixel)
```

Remark: The focus procedure of the 30m telescope has shown some odds recently. It is not unusual to have from time to time unsatisfactory focus fits which would result in very big offsets. HERA has been proven to focus very closely to the position of the other SIS receivers. Do not simply correct for proposed focus offsets of more than 2mm, but double check these results with another focus observation.

3.3 Calibration

For HERA a specific calibration system is used, consisting of dedicated hot and cold loads. The cold load is integrated into the cryostat of HERA. For the observer however this is transparent, as the OBS command `CAL COLD` is redirected to control the HERA calibration system. The only difference is that the cold load temperature may change slightly in time. Because of this the temperature of the cold load is measured and displayed in the monitor window that also displays the derotator angles. As this is not yet automatically taken into account in OBS, the observer should check this temperature at the beginning of the HERA session on the HERA monitoring screen (Tcold-eff) and if neccessary change this value for HERA1 and HERA2 in **OBS** with the usual command:

OBS> `set chop * Tcold-eff /receiver hera1(2)`

The image rejection is about 10dB in LSB tuning mode for all pixels ($Gn_i = 0.1$ for LSB and 1 for DSB tuning) and set globally for both modules at the present time.

OBS> `set gain 0.1 (1) /receiver hera1(2)`

Right now the limited precision of the image rejection factors Gn_i, the largest source of calibration errors. The limited accuracy of the knowledge of sideband rejection leads to relative calibration errors in the range of 0-10% . For high signal to noise mapping it is therefore recommended to undertake some additional steps for relative calibration or "flatfielding" (see Sect XX). A more precise rejection measurement using a line injection device is currently underway and will ultimately allow to retrieve individual rejections for each pixel from a look-up table at each frequency.

4 Spectroscopic observing modes

As HERA is a heterodyne receiver, we describe here only spectral line observing modes, although continuum mapping is possible (see section 5). In a first step the basic observing modes are described and then we explain how the various backends can be attached. Please consider that due to certain constraints (mainly computer limitations), observing modes and possible backend combinations are not independent.

- single stamps (section 4.2), take nine point maps with a single integration.
- raster maps, i.e. observations where the telescope steps through a series of points (usually fixed in the equatorial system), at each of which the telescope dwells for some integration time.
- on-the-fly maps, i.e. observations where data are taken while the telescope moves at constant velocity along a linear path in the equatorial system.

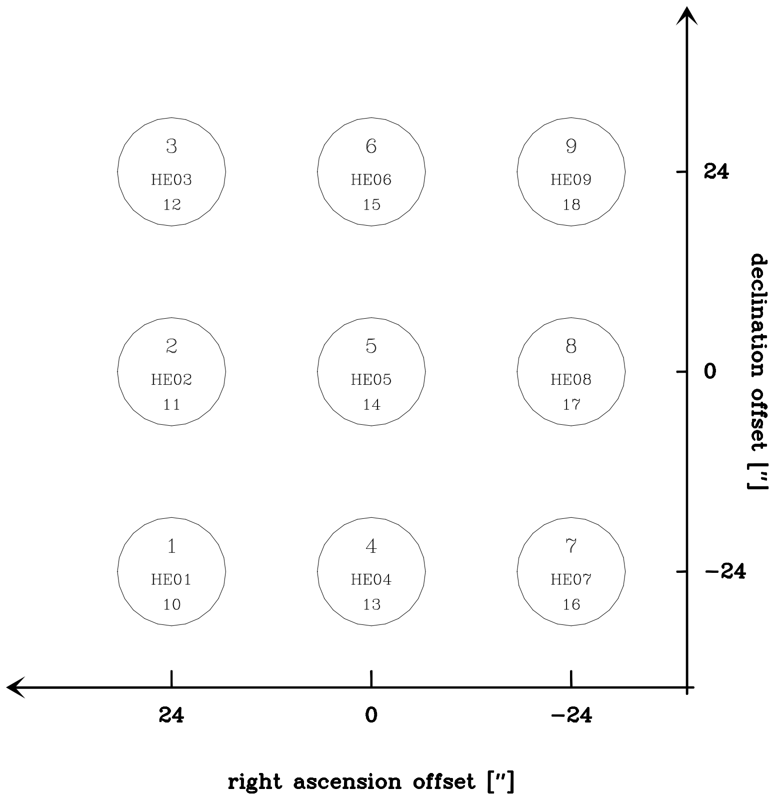

Figure 4: HERA beam pattern on the sky when set to track the rotation of the equatorial system with zero offset angle (**OBS**> `set derot 0 S`). The correspondence between pixel numbers and spectrometer sections is described in Tab. 1.

The upgraded web–based time estimator (version 2.5 and higher) handles these modes in an approximate way. Simple integrations on point sources are also possible.

4.1 General aspects

4.2 Single Stamps and Observations of Point sources

The very basic observations are single integrations with a fixed position on the sky. This will result in 18 spectra on nine position of the sky (see Fig. 4). If requested the pattern can be turned around the central pixel with the help of the derotator command. Before starting large maps it is allways recommended to do such a single shot in order to make shure that the system has been setup properly. The pattern can also be offset from the pointing center by the usual commands of OBS. If observed with the derotator tracking in the sky system the spectra will be written with the correct offsets into the spectra.30m file. The use of an array receiver offers also a certain signal–to–noise advantage compared to single pixel receivers. So far we tested several wobbler switching schemes where the source was observed more efficiently than in the 50% available with the standard wobbler

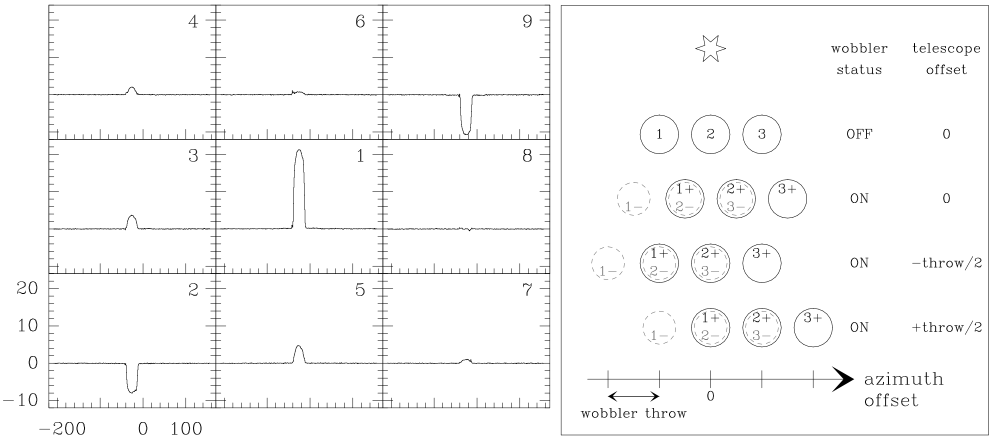

Figure 5: Wobbler–switching with HERA. Right frame: A linear sequence of pixels is considered, the center one of which is located on the pointing axis of the telescope pointed at a source. When the wobbler is switched on (wobbler throw is equal to the pixel separation) 4 beams are generated on the sky. Plus and minus signs after the pixel number indicate the polarity of the wobbler phases (negative ones are outlined in dashed lines). Left frame: Observation of an extended source, IRC+10216, in ^{12}CO(2–1). System temperatures are below 300 K, integration time is 2 min. Apart from the usual signal in the center pixel, two peripheral pixels detect a negative signal at the level of about 50%. Horizontal scales (LSR velocity, km/s) and vertical scale (antenna temperature, K) are identical for all pixels (number in the upper right corner of each spectrum).

switching mode. The aim was to combine the increased switching efficiency available with the array with the optimum baseline quality inherent in the standard wobbler–switched mode.

Our most successful schema is outlined in Fig. 5. A linear sequence of pixels is aligned with the horizontal direction in which the subreflector was wobbling. The wobbler throw is set equal to the pixel separation ($\sqrt{2} \times 24''$ when a diagonal pixel sequence is chosen, and the derotator is commanded as

OBS> `set derot −45 H`

The standard Wswitch command of OBS then executes two observations with telescope offsets of ±throw/2. The schema shows that pixel 2 sees the source in each observation for 50% of the time exactly as in standard wobbler switching with a single pixel receiver. Additionally, HERA pixels No. 1 and 3 are also looking at the source, but only during one of their phases. Since the wobbler–switched signal is the difference between the two observations, pixels No. 1 and 3 register the source signal at a level of −50%. Averaging the signals from the three pixels with their right polarity therefore increases the signal–to–noise ratio by $\frac{2}{\sqrt{3}}$ over the standard wobbler–switching.[3] In

[3] Compared to single pixel wobbler switching the signal is doubled and the noise is increased by $\sqrt{3}$. This S/N ratio increase of $\sim$ 15% is improved to $\sim$ 22% if optimum weights are used when averaging the spectra ($\frac{1}{4}, \frac{1}{2}, \frac{1}{4}$) from the three pixels.

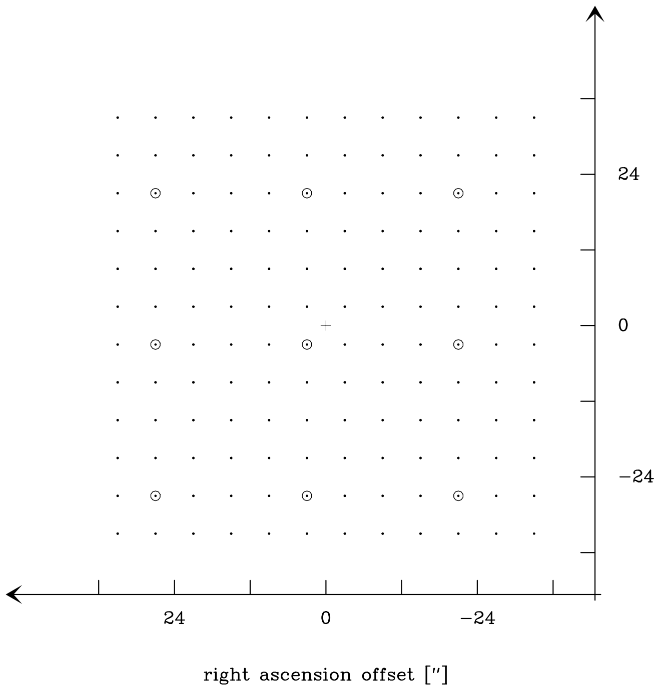

Figure 6: The simplest fully sampled raster map, called a "submap" in the text, has a size of $66'' \times 66''$. The points indicate the positions observed by stepping the telescope pointing sequentially through the 16 offset positions $\Delta\alpha, \Delta\delta = -9, -3, +3, +9''$ (sect. 4.3) relative to the telescope's pointing center (+). The circles identify the instantaneous HERA pixel pattern at telescope offset $\Delta\alpha = +3''$ and $\Delta\delta = -3''$.

our particular observation (Fig. 5) weak signals are also detected in other pixels demonstrating that the source is actually extended. The spectroscopic baseline is flat in all pixels, no deterioration was detected compared to the standard wobbler–switching with a single pixel receiver. In a more severe test, a long integration of a CO transition in a $z = 2.2$ source was made. The baselines were again flat and the line was detected.

Other wobbler switching schemes were tried where the full signal amplitude was obtained not only for pixel 1, but also for pixels 2 and 9. The S/N improvement in these more complicated schemes were however less than in the scheme described above (they would become more interesting with larger arrays).

4.3 Raster maps

A slightly more complex, but already very powerful observing mode is the raster where the telescope steps along a rectangular (in the equatorial system) pattern of points. At each point the telescope dwells for some integration time. The special OBS procedure `raster-map.pro`, not to be confused with the standard OBS raster command, is used (see Appendix A pg.19).

OBS> `@raster-map size_x size_y ppb min i_time` $\Delta\alpha$ $\Delta\delta$

where the seven arguments have the following meaning:

size_x,size_y in arc sec	map size in x and y direction, often simply in α and δ,
ppb	number of points per beam (2 for Nyquist sampling)
min	minutes before the next CAL COLD should be made
i_time	integration time in minutes, on each raster point
$\Delta\alpha$	right ascension offset of the center of the raster map with respect to the telescope pointing position, in arc sec
$\Delta\delta$	same in declination

By setting `ppb` to 2, the instantaneous HERA pixel pattern is filled in like in Fig. 6 and a fully sampled and homogeneous map is obtained consisting of 9×16 equidistant grid points. Such a "submap" covers $66''$ square, and it is command by

OBS> `@raster-map 66 66 2 min i_time` $\Delta\alpha$ $\Delta\delta$

Larger maps composed of several such submaps can be observed with the same OBS procedure. Naturally, coarser or denser sampled maps are also possible. A raster simulation program is available. [4]

The raster-map procedure comes in three varieties: position switching, wobbler switching, and frequency switching. The observer uses the standard OBS commands for setting them before the raster-map procedure is started.

position switching. The raster_map procedure asks for the position offset of the reference position with respect to the map center. It is possible to do several ON source observations per reference observation. This saves observing time, but was found to easily introduce poorer baselines. (Note that HERA operates at 1.3mm wavelength)

wobbler switching. This mode gives the best baselines on the 30m. As the wobbler throw is at maximum $240''$, map and source size must be matched carefully if the reference beams are to be kept free of signal. Note that contrary to position switching the position of reference beams refer to the current raster point (not the map center) and rotate with respect to the source.

frequency switching. For many extended sources, wobbler and even position switching may not be adequate, and only frequency switching may be practical. Owing to its position in the Nasmyth cabin, HERA has the cleanest optical path of all 30m receivers. Its frequency baselines are found to be the best recorded so far. A ripple at 6.9 MHz, probably originating from reflections between the subreflector and the mixers, dominates the

[4] This procedure `raster-map.graphic` together with the observing procedures `RASTER-MAP.PRO, OBSRASTER-MAP2.PRO and OBSRASTER-MAP4.PRO` are copied to the project home directory in the subdirectory `~/obs/HERA` on linux systems. If you do not find them there, you can copy these from `/mrt-lx1/vis/default/obs/HERA/`

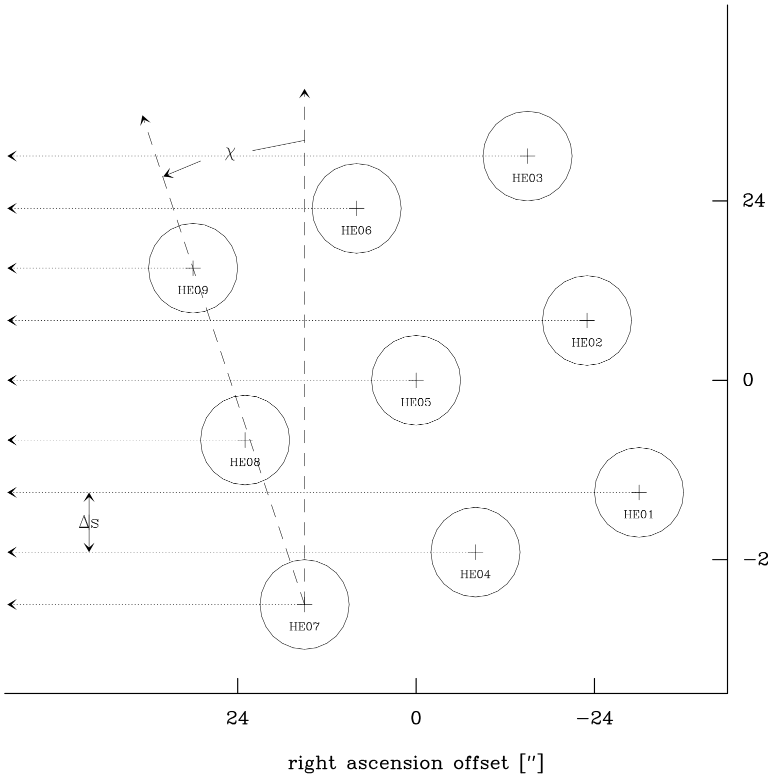

Figure 7: Orientation of the HERA pixel pattern used in the coarsely sampling OTF mapping mode. The pixel pattern is rotated by $\chi = 18.5°$ in the equatorial system. This results in a uniform OTF map where the scanning lines (parallel to right ascension) are separated in declination by $\Delta\mathrm{s} = 7.6''$. If uniform coverage is to be extended toward the north, a second map is made with a declination offset of $\Delta\delta = 9 \times \Delta\mathrm{s} = 68''$.

spectroscopic baseline. Flat baselines are obtained by setting the frequency throw equal to this value or multiples of it. Satisfactory performance was obtained up to throws of 6 × 6.9 MHz (54 km/sec).

Frequency switching rates up to 10 Hz were successfully tested with both HERA modules were connected to the VESPA backend (sect. 4.1 and Tab. 3) set to 80 kHz resolution and 40 MHz bandwidth, i.e. 50% usage of VESPA capacity. However, there is usually no need with the raster-map procedure to switch faster than about 1 Hz.

4.4 On–the–fly maps

OTF mapping, the most powerful spectroscopic mapping mode on the 30m, becomes even more powerful with HERA. So far, we have expanded on the single receiver OTF in the following two ways:

- scanning procedures, some with special orientations of the HERA beam pattern, reduce the time for mapping by factors somewhere between 3 and 9.

- frequency switching is possible with the VESPA backend, eliminating the need for reference observations.

Scanning procedures. We support the following three scanning procedures, i.e. observing procedures exist, data reduction is tested, and they are handled by the web–based time estimator (version 2.4 and higher). These three scanning procedures are associated with different orientations of the beam pattern (rotation angle χ) with respect to the scanning line (taken here as right ascension).

◇ zero rotation (labeled in the Time Estimator: SL–OTF, not inclined)

◇ coarse sampling (SL–OTF,8 arc sec)

◇ oversampling (SL–OTF, 4 arc sec)

In the zero rotation mode, the beam pattern is scanned parallel to right ascension like in Fig. 4. The points on each of the 3 scan lines are sampled three times, but the area between the three horizontal beam rows is not sampled. This mode may be useful for obtaining a first quick look on a weak extended source.

In the coarse sampling mode, the beam pattern is rotated by $\chi = 18.5°$. This results in a slightly under-sampled map where the scan lines are separated by $\Delta s = 7.6''$ (Fig. 7). The map is homogeneously sampled apart from $60''$ wide vertical margins at the left and right ends of the scanning lines.

In the oversampled mode, the beam pattern is rotated by $\chi = 9.5°$. This generates three bundles of three scan lines spaced by $\Delta s = 3.9''$, the separation between the bundles being $\Delta\delta = 3 \times \Delta s$. Two OTF scans must therefore be made (see Fig. 8) which are offset by $\Delta\delta$ in declination. The scan direction of these two OTF scans may be the same, as shown in the figure, or opposite to each other. At the end, a homogeneously sampled map is obtained again, apart from $56''$ wide lateral margins.

Note that for maps smaller than typically $2'$ on a side, the size of these margins are a large fraction of the total area to be mapped. Such small maps are therefore more efficiently done in raster mode.

Total power OTF is available with VESPA, WILMA and the filter spectrometers. The spectrometer readout rates, and thus implicitly the scanning speed, are limited to 0.5 Hz. Observations with the 4 MHz filterbank clearly demonstrate the sensitivity of this observing mode to sky noise and gain variations in the receiver. Together with the unavoidable nonlinearities of the backends sky noise and receiver gain variations lead to base line distortions and (for the correlators) to platforming. Good and stable weather conditions are therfore mandatory for this observing mode..

The gain drifts are related to the temperature fluctuation of the cryostat which has an irregular cycle period of 3 to 5 min and sometimes intrinsic mixer instabilities. Under good weather conditions ($T_{sys} \sim 300$ K) the drifts which may be as rapid as a few seconds reach amplitudes of 0.2 K. The gain drifts affect different sections of the bandpass differently, and are statistically less affected near the times when a reference observation is made.

Software is being developed to correct for the gain drift induced baseline variations. The mainly concerned extragalactic observers are invited to contact H. Wiesemeyer wiesemey@iram¡.fr). about its current state. Furthermore, it is planned to monitor the physical temperature of the mixers and use this information to re–calibrate the receiver gain.

Frequency switched OTF is available with the same hardware limitations as with rasters (sect. 4.3). A high (> 1 Hz) frequency switching rate is however more important here than with rasters. Note that frequency switching OTF with VESPA is currently limited to a use of not more than 50% of VESPA. This limitation is due to the limited readout speed of the current computer system.

4.5 Ugly details

Rasters are currently handled in a rather heterogeneous way. The new procedure `raster-map.pro` introduced for HERA generates the desired position stepping sequence of the telescope, complete with flexibly interspersed calibrations. But it cannot do more than one ON/OFF. Another procedure `obsraster-map.pro`, invoking the traditional OBS raster command, does exactly that. There are two examples given for `obsraster-map.pro`: `OBS-RASTERMAP2.PRO` and `OBS-RASTERMAP4.PRO` for 2 resp. 4 ON– per OFF–source integrations. These procedures can be found as described in the footnote on pg. 13. **Frequency switching** gives very good results with HERA. The `raster-map` procedures can be combined with frequency switching, but the `obsraster-map` should not be used as useless OFF source integrations are done.

4.6 Special Observing Modes

4.6.1 Rotated coordinate systems

OTF mapping in coordinates other than the equatorial system are also possible. If such a system, possibly aligned with a molecular outflow, is rotated by the angle κ relative to the equatorial system, the derotator has to be given the same angular offset. The corresponding OBS command then is

OBS> `set derot` $\chi - \kappa$ `S`

where χ is as above the angle induced by the OTF mapping mode. This situation is depicted in Fig. 9 where the array scans along the λ axis of a descriptive system centered at (α_0, δ_0) and tilted by the angle κ with respect to the local meridian. Change your observations into a rotated coordinate system needs some input into the hidden parameters of OBS (OBSINP) and a special setup for your source coordinates; contact A. Sievers in case.

4.6.2 Backends

HERA as a general purpose multi–beam receiver has strong demands on spectral backends. Tab. 2 lists the available backends.

Table 2: Backends for HERA

type	channel spacing kHz	bandwidth MHz	number of units	status
4MHz FB	4000	1024	9	available
VESPA	20 – 1250	20 – 640	9 – 36	available
WILMA	2000	1024	18	available

The filterbank consists of 9 units with 256 channels each. The channels have a half-power width (resolution) of ca. 5 MHz, corresponding to a noise–equivalent bandwidth of 6.4 MHz. Channel spacing is 4 MHz. The 9 units were successfully taken into operation in February 2003. The OBS command for setting up the filterbank is

OBS> `4MHz /Receiver HERA1 or HERA2`

The uncalibrated raw data are written to a LINUX computer. An automatic calibration task generates a spectra.30m file which can be analyzed with CLASS. The 4 MHz data are identified by their "set telescope" name. The central pixel, e.g., is designated as `30M-4M05-HERA`.

The digital correlator VESPA offers spectral resolutions in the range 20 - 1250 kHz (Tab. 3). Up to 4 spectral bands per pixel are available for the current 9–pixel array. The 4 bands can be placed anywhere in the lower half of the 1 GHz wide IF range. A typical OBS command for setting up the correlator is

OBS> `VESPA 1 320 160 0.0 /Receiver HERA1 or HERA2`

where one section of VESPA is connected to each HERA pixel. Each section has a channel spacing of 320 kHz, 160 MHz of nominal bandwidth, and an offset of zero (in MHz) from the IF center. This configuration uses 50% of VESPA hardware, so that more sections could be connected, possibly at off–center frequencies.

Uncalibrated VESPA data from HERA are written by the VAX in the usual raw data format. They are automatically calibrated, displayed by RED, and written to the usual spectra.30m file. The calibrated HERA spectra are identified in CLASS by their "set telescope" name. The central pixel, e.g., is designated as `30M-V01-HE01` where `V01` stands for the first frequency band connected to the current vertical polarization array and `HE01` is pixel No. 1 of HERA (see also Tab. 1).

All VESPA configurations are available with all observing modes. Readout speed (dump time in OTF, phase time in switching modes) is however limited to ca. 10 000 channels per sec by the VAX antenna control computer. If the full number of VESPA channels is connected, read out should not be made faster than once per 2 sec.

The new correlator is now the wide band (usuable bandwidth 18 x 930 MHz) WILMA backend offering 9 + 9 spectral bands. The setup in OBS is simple, the following

OBS> `WILMA A /Receiver HERA1 or HERA2`

sets the first 9 spectral bands, and

OBS> `WILMA B /Receiver HERA1 or HERA2`
sets the second 9 spectral bands.

The distribution of the 4MHz and WILMA backends and HERA1 and HERA2 is now done automatically by a new 'distribution box'. Only the 4MHz has to be switched manually between single pixel receivers and HERA.

Table 3: VESPA configuration table.

channel spacing	bandwidth, MHz		number of channels		usage
kHz	nominal	actual	raw data	RED calibrated	%
1250	160	141.2	1152	9×113	25
1250	320	281.2	2304	9×225	50
1250	480	421.2	3456	9×337	75
1250	640	511.2	4608	9×409	100
320	80	70.3	2304	9×225	25
320	160	140.3	4608	9×449	50
320	240	210.3	6912	9×673	75
320	320	280.3	9216	9×897	100
80	40	35.1	4608	9×449	25
80	80	70.1	9216	9×897	50
80	120	105.1	13824	9×1345	75
80	160	140.1	18432	9×1793	100
40	20	17.5	4608	9×448	25
40	40	35.0	9216	9×896	50
40	60	52.5	13824	9×1344	75
40	20	70.0	18432	9×1792	100
20	20	17.5	9216	9×896	50
20	40	35.0	18432	9×1792	100

5 Data reduction

Extensions for HERA Data reduction for HERA data is very similar to the one for single beam receivers. The only difference is that the raw data contain now information about the derotator angle offset and the actual tracking system. Up to now RED and OTFCAL generate only for observations with derotation in the equatorial (SKY) system the correct pixel offsets for all HERA channels. For these standart observations the user will obtain calibrated single or otf 30m spectra with the correct offsets exactly equivalent to any other 30m spectral data files. A current draw back is that currently OTFCAL and RED use the nominal derotation angle (instead of the actual). The usually negligtible errors in servoing of the derotator will not be taken into account. Unfortunately this leads to wrong offsets in case of a stuck derotator. Data are assigned to the various pixels (together with the backens) within the -telescope- parameter of the 30m scans.

NEW: Calibration via ODP All the spectral line data, including some OTF maps and the 4MHz data are now calibrated on-line on our linux file-server mrt-lx1. For details of Online Data Processing (ODP) see the documentation
http://www.iram.es/IRAMES/documents/projectDataProcOnline/Current/MAIN.html.

We say 'some' OTF maps, since we calibrate only maps that have a subscan on the reference position at the start and at the end of the on-source subscan(s). Basically a pattern of RFF...R, that may also repeat.

The calibrated spectra are written in CLASS format to the file:
/mrt-lx1/mrt/data/(project-directory)/spectraOdp.30m and and intermediate spectra used for "on–line display" are written into the file:
/mrt-lx1/data/mrt/(project-directory)/spectraPlot.30m .

NEW: On–line display for ODP. The on–line display for ODP is not started automatically, the observer needs to start a terminal session on mrt-lx1.iram.es and then type

/mrt/tcs/tools/odpPlot

At present this is only a "quick look" using CLASS to display the spectra as they are produced, not yet a comfortable viewer.

6 Appendix A: raster-map.pro

```
!**********************************************************
!
!-- RASTER mapping without cross calibration consideration
!
!-- Inputs:
! size       = sx x sy
! sr         = sampling-rate
! cal_inter  = time between 2 CAL COLD
! t          = integration time per point
! omx        = offset of the center of the map along X
! omy        = offset of the center of the map along Y
!
!-- Outputs:
! the offsets of the central channel of HERA
! the time needed to make the map
!
! PHB -- 17-jun-2001
! PHB -- 25-jul-2001
!
!**********************************************************

! -- INPUTS
define real sx sy
define real sr
```

```
define real cal_inter t
define real omx omy

let sx        = &1
let sy        = &2
let sr        = &3
let cal_inter = &4
let t         = &5
let omx       = &6
let omy       = &7

! -- OUTPUTS
define real offx offy
define real int_time

! -- LOCALS
define integer nmx nmy nummap
define integer nstep n1dir
define real d ds
define integer m l p q
define real a
define real beam
define real cal_time
define real fac
define integer cal_num count
define real offx0 offy0
define real efsx efsy

! ****************************************************


!--------- Definition of some constants relative to HERA
let beam = 12.
let a    = 24.
let d    = beam|sr

!--------- some submap parameters
! ds = size of the submap (same in both dir.)
! np = nb. of points in one submap
let ds      = 1.5*2*a-d
let n1dir   = int(a|d)
let nstep   = n1dir**2

!--------- nb of submaps along both directions
let fac = sx|(ds+d)
if (mod(fac,1).lt.0.5) then
let nmx = int(sx|(ds+d))
```

```
else
let nmx = int(sx|(ds+d))+1
endif
let fac = sy|(ds+d)
if (mod(fac,1).lt.0.5) then
let nmy = int(fac)
else
let nmy = int(fac)+1
endif
let nummap = nmx*nmy
let efsx   = nmx*(ds+d)-d
let efsy   = nmy*(ds+d)-d

!--------- Determination of the total integration time
let cal_time = 1.|5. !15s to make a CAL COLD in min.
let int_time = nstep*nummap*2*t
let int_time = int_time+cal_time*int_time|cal_inter
let int_time = int_time*1.30
let cal_num = int(cal_inter|t)-1

!--------- Determination of the offsets of the central channel
! offsets are relative to the source in OBS
let count = 0
        let offx0 = omx-efsx|2-2.*d-ds+a
  let offy0 = omy-efsy|2-2.*d-ds+a
SET ANGLE SEC

pause "Ready to start ?"
pause "Derotator...?"
CAL COLD
SET OFFSETS BASIS
for nsubmap 1 to nummap
  let q = int((nsubmap+nmx-1)|nmx)
  let p = nsubmap-(q-1)*nmx
  for n 1 to nstep
    let count = count+1
    let l = int((n+n1dir-1)|n1dir)
    let m = n-(l-1)*n1dir
    let offx = offx0+(p+m)*d+p*ds
    let offy = offy0+(q+l)*d+q*ds
    OFFSETS offx offy /BASIS
    if count.eq.(cal_num+1) then
CAL COLD
BELL
BELL
let count = 0
    endif
```

```
    START
    SAY "SUBMAP  OFF_LAM  OFF_BET"
    SAY 'nsubmap' 'offx' 'offy'
  next
  BELL
  pause "SUBMAP #"'nsubmap'
next

BELL
say "............MAP FINISHED"
return
```

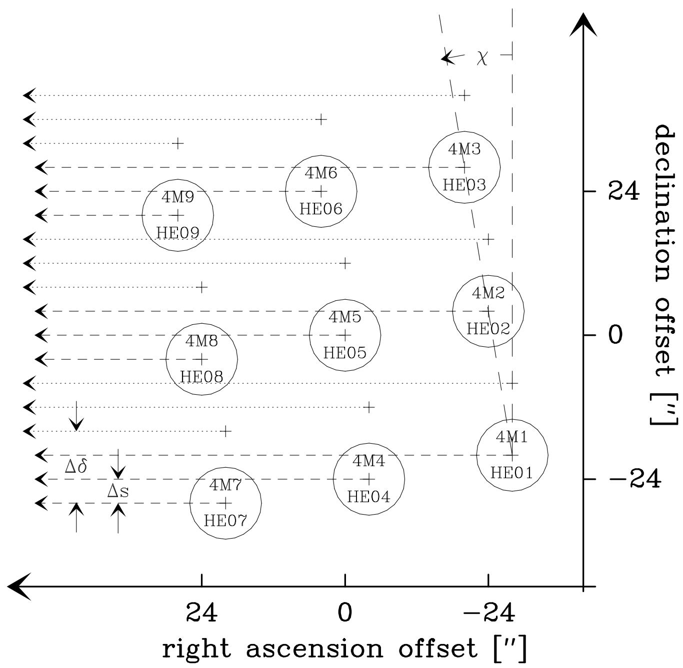

Figure 8: Orientation of the HERA pixel pattern used in the oversampling OTF mapping mode. The pixel pattern is rotated by $\chi = 9.5°$ in the equatorial system. Two OTF scans are made separated by $\Delta\delta = 3 \times \Delta\mathrm{s} = 12''$ in declination. A second pair of such maps (not shown), offset in declination by $6 \times \Delta\delta = 71''$, extends uniform coverage to the north.

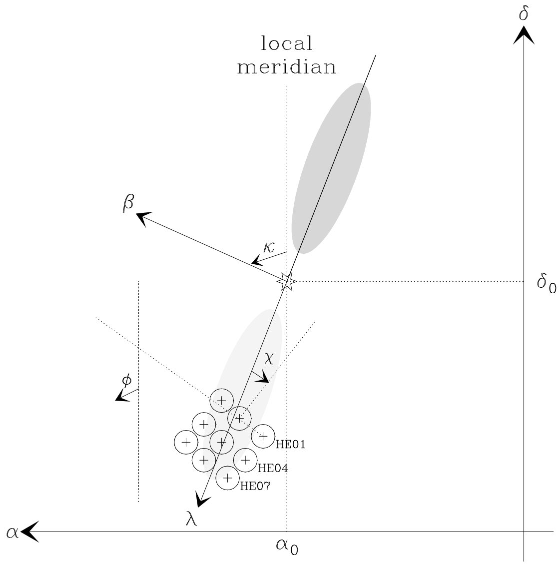

Figure 9: A rotated coordinate system is illustrated with an outflow source centered on the star (∗) which is located at α_0, δ_0 in the equatorial system. The new coordinate system has its equator, λ, aligned with the outflow lobes, and the orgin of the new system is at the star. The latitude, β, makes an angle κ with the local meridian.